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Development Aid and the diffusion of technology: Improved cookstoves in Kenya and Rwanda

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Abstract

This paper analyses the role of official development assistance (ODA) in the evolution of Technological Innovation Systems (TISs) of improved cookstoves in Kenya and Rwanda. Functionally balanced TISs are central to the diffusion of new technologies and practices. We find that ODA has significantly influenced major innovation activities related to improved

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cookstoves in both Kenya and Rwanda over the last 30 years. However, donors' funding has been focused mainly on the development and diffusion of technical knowledge. We find that this pattern of ODA support has not fostered balanced and effective Technology Innovation Systems, and that this has contributed to the failure to achieve widespread diffusion of improved cookstoves. We develop a quasi-evolutionary model for the long-term and systematic ODA support of innovation systems to build sustainable renewable energy TISs in developing countries.

Key words: Official Development Assistance (ODA); renewable energy; technological innovation systems; functions approach to innovation systems; cookstoves; Africa

1 Introduction

Since the 1970s, international aid donors have made efforts to improve energy efficiency and energy access in developing countries. From the early 1970s to mid-1980s, an increasing amount of development assistance was channeled to energy in developing countries reaching over $6 billion in 1985 (Piebalgs, 2012). From the 1980s to the early 2000s, aid to energy declined to $3 billion, whereas recent trends show an increasing interest and reviving optimism in the donor community about support for the energy sector in developing countries. By 2010 the annual average aid commitment to energy has reached to about $10 billion (Piebalgs, 2012).

Although most official development assistance (ODA) is for large-scale electricity generation, it also includes the promotion of small-scale and decentralized energy technologies (e.g. biogas systems, photovoltaic and improved cookstoves) (Martinot et al. 2002). However, historically, the effectiveness of aid in achieving dissemination and use of small-scale renewable energy technologies in developing countries has been mixed at best (Kozloff, 1995; Martinot et al., 2002).A recent study of donor-funded projects in Philippines, for example, shows that while donors have played some beneficial roles, such as in policy advice, they have failed to meet stated objectives due to lack of coordination across interventions (Marquardt, 2015).

The major aim of this study is to explore the effectiveness of ODA in promoting energy efficient technologies. We define ODA broadly as all types of contributions from development partners, such as multilateral organizations, international aid donors, local and international non-governmental organizations (NGOs) and international research institutes for the development, adaptation, diffusion and use of energy efficient technologies. The role of ODA on development more broadly has been discussed by other authors, such as Easterly (2006) and Moyo (2009). Here we only focus on highlighting the role of ODA in promoting energy efficiency through the development and diffusion of improved cooking technologies in two developing countries.

Improving the effectiveness of aid to energy gained a central place in aid policy debates in the 1990s[2]. This resulted in changes in support for renewable energy technology through development aid. More recently, there has been a focus on market and enterprise development, in which donors share risks and costs of sustainable energy technologies (Piebalgs, 2012). While the new paradigm endorses a market-oriented approach, with importance placed on the role of

[2] The early policy efforts of improving aid effectiveness can be traced back to a statement by Organization for Economic Co-operation and Development-Development Assistance Committee (OECD-DAC) in 1995. The 2005 Paris Declaration and the 2008 Accra Agenda for Action and the Millennium Development Goals (MDGs) are among the recent commitments of developed and developing countries to improve the effectiveness of aid (Kindornay & Reilly-King 2013).

the private sector (Piebalgs, 2012; Kindornay & Reilly-King, 2013), it has not, in most cases, achieved breakthroughs in the market penetration of new energy technologies. This is mainly because the full range of institutions, capabilities and activities leading to the absorption and diffusion of technologies are generally fragmented or absent in least-developed country contexts.

Over the last decade, a growing body of research has suggested that absorptive capacity for low carbon technologies can be developed by facilitating a comprehensive approach to the emergence, growth and functioning of innovation systems (see e.g. Sagar and Holdren, 2002; Bruggink, 2012). Yet, little research has investigated what role development aid has played and can play in the evolution of innovation systems of renewable energy technologies in least-developed countries. Building on earlier empirical analyses of the evolution of biogas and improved cookstove Technological Innovation Systems (TISs) in in East Africa (reported in Tigabu et al., 2015a, 2015b, 2015c), this paper analyses the role of development aid in the evolution of improved cookstove innovation systems in Kenya and Rwanda. Building on this historical analysis, it develops a conceptual proposal for effective aid interventions which aim at supporting innovation systems for renewable energy in developing countries.

The paper is organized as follows. Section 2 presents an overview of changing technology diffusion perspectives and how this has influenced aid strategies in developing countries, particularly in the rural renewable energy sector. It sets out the link between innovation systems, absorptive capacity and technology diffusion, and goes on to argue that public policy, including development aid, should be directed at creating an enabling framework for greater diffusion of renewable energy technologies. Such enabling frameworks include specific conditions and policies that accelerate diffusion of renewable energy technologies (see Haselip et al., 2011 for more on the concept with case studies). Section 3 and 4 present a brief overview of Technological Innovation Systems approach and the methodology used in this study. Section 5 analyses the role of ODA in the functional evolution and accumulation of improved cookstove technology innovation systems (TIS) in Kenya and Rwanda over periods going back to the 1950s. Section 6 presents a conceptual proposal for sustainable energy aid intervention from a TIS perspective, and Section 7 presents concluding remarks.

2 Historical overview on perspectives of technology diffusion and development aid in developing countries

Supporting the diffusion of technologies in developing countries has been among the areas that donors and non-governmental organizations (NGOs) have focused on since the 1960s. Finding a feasible approach to support technology diffusion and adoption has therefore been a crucial question. In this section, we summarize changing donor approaches to the diffusion of energy technologies.

Diffusion of technologies in rural areas of developing countries caught the attention of social researchers in the 1960s, inspired by an emphasis placed on technology transfer by international development assistance organizations to alleviate poverty (Ruttan, 1996). During this period, most diffusion studies (mostly in agricultural sector) focussed at identifying variables (e.g. socio-economic and behavioral traits) related to ‘innovativeness’ of individuals and understanding the role of communication channels at various stages in the innovation-decision process (Rogers, 1995).

This early perspective was criticised for its failure to take into account the characteristics of technologies. Beginning in the 1970s, a shift in perspective took place, characterised by an emphasis on attributes of technologies in relation to the social, economical and cultural attributes of adopters (Barnett, 1990). This approach, associated with the Appropriate Technology Movement, built on the view that adoption of technologies was linked to the modification of technologies to developing country contexts and users' needs (Bonair et al., 1989). In this approach, designing technologies fitted to specific contexts of technology adopters was considered crucial to their successful adoption and utilization. Appropriate technologies were characterized as being small, simple, labour-intensive, energy efficient, and environmentally sound (Akubue, 2000). The appropriate technology approach focused on supporting people in rural areas to apply indigenous knowledge, through training and capacity building, to produce 'backyard' technology on one hand, while deploying cheaper and simple technologies suitable for village-level uses on the other. There was little commercial focus (Kaplinsky, 2011).

Lessons from project implementation further emphasized the need for users to participate in the design and testing of 'appropriate' technologies (Gamser, 1988). Gender issues were emphasized, with women given roles as designers and beneficiaries in development projects (State & Mavima, 1996). In the rural energy sector, donor interventions at this time largely followed a technology-focused and project-based approach in which the aim was to identify and promote the 'right' energy technologies, including free provision of equipment (Kozloff, 1995;

Martinot et al., 2002). Such interventions were generally considered to be ineffective in practice. In their review of the historical role of donor interventions, Martinot et al. (2002: 313) noted that "… much of the development assistance, particularly aid for rural areas, focused on technical demonstrations or on projects that were narrowly self-sustaining but could not be replicated. Projects often did not demonstrate institutional and commercial viability, and lacked mechanisms for equipment maintenance, sustainable sources of credit and expertise, and incentive structures for sustained operating performance."

Recent research on the diffusion of renewable energy technologies in least-developed countries suggests that elements of these approaches persist in international policy. Econometric models point to household socio-economic characteristics, technological attributes, and communication and institutional incentives as the main explanatory factors of adoption decisions by beneficiaries (see e.g. Walekhwa et al., 2009; Gebreegziabher et al., 2012).

The paradigm guiding donor policies however has changed its emphasis from technology-focused to market-oriented approaches. This change has been characterized by a focus on the private sector and entrepreneurship in which donors aim to fill financial, technical and regulatory gaps in the promotion of energy and environmental technologies (Martinot et al., 2002; Kindornay & Reilly-King, 2013). Recent attention to the business value of the 'base of the economic pyramid' (BOP) (4 billion low-income people with an aggregate market potential of $ 5 trillion) to transnational corporations (TNCs) (Prahalad & Hart, 2002; Hammond et al., 2007) has also had an influence. Most donors follow 'neo-liberal' strategies to catalyse private sector development, with a limited role for the state (government) of recipient countries (Kindornay &

Reilly-King, 2013). Neoliberalism policies have been followed by many developing countries, although some countries have undertaken post-neoliberal market re-reforms, moving away from market policy prescriptions (see Haselip & Potter, 2010 for the case of Argentina). Market-based mechanisms have also influenced technology transfer perspectives within climate change negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) (Haselip et al., 2015a).

On the other hand, since the early 1990s, new insights into the diffusion of energy technologies in developing countries have been suggested (see e.g. Barnett, 1990; Bhatia, 1990). These studies view adoption and diffusion of renewable energy technologies from a wider perspective, including the importance of user capabilities, the market and regulatory context, interactions among users, producers and other actors, and market preferences as determining factors. Such insights are in line with modern innovation theory, which stresses that innovation, diffusion and adoption are inter-related processes, occurring in specific enabling institutional environments, including but not limited to markets.

Successful adoption of technologies entails skills to operate and maintain, as well as the capacity to modify a technology to meet changing needs and circumstances. The development of entrepreneurship, learning and innovation capacities to acquire, operate, modify and assimilate technologies have been recognized as a crucial factor determining technical change and economic growth in developing country settings (Nelson & Pack, 1999; Lall, 1992; Hobday, 1995). Ockwell et al. (2008), with reference to low-carbon technologies, have pointed out the need not only for equipment deployment but also for the development of 'know-how' to successfully assimilate it. With respect to small-scale energy technology diffusion in less-developed countries, Barnett (1990: 543) argued that "... the capability to manipulate a technology over time and to ... improve performance and efficiency is often the most difficult capability to acquire." The importance of enabling frameworks and governance approaches to ensure capability development has increasingly received attention form policy and academic circles (see for example Haselip et al., 2015a).

3. The Technological Innovation System (TIS) approach

Over the last two decades or so the development of absorption capacities has increasingly been contextualised through evolutionary and systemic approaches. Among them is the Technological Innovation System (TIS) approach, defined by Carlsson and Stankiewicz (1991:111) as "… network(s) of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology." These innovation systems fulfil crucial functions that build up innovation capability of firms and other agents, and thereby influence the development, diffusion and use of new technologies. Table 1 provides a list of seven functions and brief descriptions based on Hekkert et al. (2007a). Detailed and elaborated reviews on the theory of TIS and functions can be found in Hekkert et al. (2007a) and Bergek et al. (2008).

Table 1: Functions of TIS.

Entrepreneurial activities are activities related to commercial startups diversifications and experimentation around a new technology.
Knowledge development refers to activities that are related to learning about the technical social and economic

aspects of a new technology.
Knowledge diffusion refers to activities that are focused on diffusion of information creation of awareness and capacity and sharing of resources among actors.
Guidance of the search involves creaction of expectations and optimism about the future of a new technology.
Market formation refers to activities and processes that can create a niche for a new technology.
Resource mobilization refers to financial and human resources and infrastructures that are mobilized for a new technology development and diffusion.
Creation of legitimacy refers to activities that legitimize a new technology.

In this approach, for a technology to be diffused and adopted successfully, the development of a (functionally) balanced and mature innovation system is critical (Tigabu et al., 2015b). Balanced TISs are those who have achieved some level of accumulation of all the seven functions over a period of time. There may be quantitative (number of initiatives, size of budgets) or qualitative (number of events, existence of business networks) evidence for these innovation system functions. While there is an extensive literature on systems of innovation, no agreed criteria for their measurement exist, partly because they include institutional, economic, technological and cultural features.

Tigabu et al., 2015b, and others such as Agbemabiese et al., 2012, suggest that the TIS framework is a useful analytical basis for conceptualizing and analyzing the diffusion of sustainable technologies in developing countries. In this study, we apply the TIS approach to examine the role of ODA retrospectively over periods of several decades in the promotion and diffusion of improved cookstoves in Kenya and Rwanda.

4. Methodology

The purpose of this study is to gain insights into the role of development aid in the emergence and evolution of innovation system functions related to improved cookstoves in Kenya and Rwanda. Functional evolution refers to the historical dynamics of a TIS in terms of the seven functions set out in Table 1 above. To achieve this, we mapped the major activities and processes contributed by major actors and institutions involved with improved cookstove technology in Kenya and Rwanda, with a historical perspective. This was done by reviewing published and unpublished secondary sources, such as case studies, project reports, books, policy papers, leaflets, brochures and magazines.

Additionally, data were gathered through interviews with 50 key informants in Kenya and Rwanda (see Table A1 in appendix for categories of key informants). The interviewees included actors active in the promotion of the improved cookstoves, including biomass energy experts. Through an iterative process, we attempted to collect as many event data as possible (see Table S1 and Table S2 within the Supplementary Material for the complete list of events mapped). Interviews and supplementary data collection continued until a clear picture of the functional evolution of the two TISs emerged and no more new major actors, relationships and events could be uncovered.

One aspect of this analysis was a need to aggregate events into themes or indicators. A given indicator activity was taken as evidence of a contribution to an innovation system function. In this study, the activity themes of events were coded into the functions using a coding scheme of indicators (Table 2).

Table 2: Indicators for the functions

Function	**Indicator activities**
Entrepreneurial activities	• Technology manufacturing and/or installing • Entry of firms/ producers
Knowledge development	• Conducting market surveys/feasibility studies/pilots • Performance testing, Developing promotional materials • Developing new designs/prototypes • Adapting or modifying new models • Developing complementary technologies • Assessing biomass energy use trends (fuel utilization surveys) • Assessing the presence of biomass resources for fuel • Assessing availability of raw materials for technology production • Conducting impact assessments
Knowledge diffusion	• Training (of technicians or constructors) • Conducting awareness campaigns • Organizing conferences/workshops/seminars/meetings • Demonstrations and exhibitions
Guidance of the search	• Setting targets • Designing favorable regulations and policies • Setting expectations • Providing awards • Providing directions/showing interest • Publicizing research outcomes
Market formation	• Subsidization (Sharing the cost of investment) • Standardization • Setting tax incentives

	• Public procurement • Regulatory reform
Resource mobilization	• Providing financial incentives, grants (Funding) • Providing loan (credit) • Mobilizing human resources, such as hiring consultants and technical staff • Providing improved tools (equipments)
Creation of Legitimacy	• Conducting advocacy activities (lobbying)

Subsequently, using the event data, a summary narrative was generated, including quantitative analysis of functions supported by different groups of actors (see Table S1 and Table S2 in the Supplementary Material).

5. Role of development aid in the functional accumulation of improved cookstove innovation systems in Kenya and Rwanda

In this section, we assess the role of development aid in the functional accumulation of improved cookstove innovation systems in Kenya and Rwanda. Functional accumulation in the context of this study refers to the cumulative number of events corresponding to specific functions within particular period of time.

Improved cookstove refers to stoves that efficiently burn traditional fuels, such as charcoal and firewood in a household and sometimes in institutional settings, such as schools. A typical example of such stoves is the Kenyan Ceramic Jiko (KCJ). The Kenyan improved cookstove TIS emerged in mid-1970s (see Table S1 and Table S2 in the Supplementary Material for a complete list of functions and their key financing actors). Over the next decade, *knowledge development*, *knowledge diffusion* and *resource mobilization* functions became relatively well developed. The role of development aid in the emergence of these functions was crucial (see Table 3). International agencies, such as the Swedish Beijer Institute, contributed to the *knowledge development* function (e.g. conducting wood-fuel consumption trend assessments), which had contributed to Guidance of search function. Other development agencies, such as United Nations Children's Fund (UNICEF) and the Bellerive Foundation of Geneva, funded improved cookstove design activities *(knowledge development)*.

The 1981 United Nations Conference on renewables was a significant influence, leading to the development of other functions, such as *resource mobilization* supported by development agencies, such as the United States Agency for International Development (USAID). These resources were further used for *knowledge development* (stove prototype development and testing) and ultimately *knowledge diffus*ion (public campaigning and training of stove producers) around urban charcoal stoves. From the mid-1980s to the 1990s, *knowledge diffusion*, *resource mobilization* and *knowledge development* continued to be relatively well supported by aid agencies. Development partners, such as GTZ, Norwegian Agency for Development Cooperation (NORAD) and Appropriate Technology International (ATI), mobilized *financial resources* that funded *knowledge development* (e.g. rural and institutional stove design development) and *knowledge diffusion* (e.g. training of womens groups on rural stove production and marketing) (see Table 3).

However, at this stage, aid interventions became increasingly isolated from one another in time and space. Development agencies, such as Intermediate Technology Development Group (ITDG), focused on skill development amongst women's groups, without much regard to other sets of local actors working in the cookstove sector in Kenya. From 1995 to 2011, development partners broadly continued this support for *knowledge diffusion* activities. Generally, 75 % the major activities related to the build-up of a cookstove innovation system in Kenya from the mid-1970s to 2011 were partly -or fully- sponsored by development aid. Specifically, development aid had financed 83% of knowledge development activities and 79 % of knowledge diffusion-related activities over the entire period of our observation whereas its contribution to *entrepreneurial activities*, *market formation* and *creation of legitimacy* was comparatively limited (Table 3). The continued focus on the design of stoves, training of producers (mainly women), and public campaigning suggests that the 'appropriate technology' approach continues to have a significant influence on development aid approaches in this case.

Table 3: Contributions of development agencies to the functioning of improved cookstove TISs in Kenya (1976-2011)

	1976-1984	1985-1995	1996-2011	Total no. of events
Entrepreneurial activities	0	1(33%)	2(50%)	4
Knowledge development	**10(83%)**	**15(88%)**	**15(83%)**	**18**
Knowledge diffusion	**7(78%)**	**15(83%)**	**19(79%)**	**24**
Guidance of the search	4(67%)	5(71%)	6(50%)	**12**
Market formation	0	0	0(0%)	2
Resource mobilization	**7(88%)**	**17(95%)**	**21(96%)**	**22**
Creation of Legitimacy	0	0	0(0%)	1
Estimated diffusion rate (%/year)*	0.12	1.01	2.44	

*Source: Tigabu et al. (2013c).

Notes:

- The values of each function supported by development aid are cumulative; i.e. the total number of events supported by development aid beginning from the emergence of the TIS. For example the values given in the period 1985-1995 are the cumulative number of donor-funded events from 1976-1995
- ‘Total number of events’ refers to the cumulative total number of events that were supported by both governmental and non-governmental actors.
- The values of functions represent the cumulative frequency of major events directly sponsored or indirectly supported by development agencies and the percentage (in brackets) of these events of the cumulative number of events corresponding to that function within the specified period.
- Periods are specified on the basis of distinct functional patterns of the TIS.

In Rwanda improved cookstoves were introduced somewhat later, in the early 1980s. In the early years, development agencies, such as the Dutch SNV, provided most of the funding for national programmes (*resource mobilization*) (see Table 4). This financial resource was devoted especially to *knowledge diffusion* function (mainly public awareness campaigning). A stove program funded by the World Bank also contributed *knowledge development* (charcoal stove model testing) and *knowledge diffusion* (training women’s groups and information campaigning). From 1995-2000, there were no improved cookstove-related activities due to the civil war of 1994. Over the last decade, the TIS has re-emerged and added additional *knowledge diffusion* and *knowledge development* functions. Here too, development agencies, such as United States Agency for International Development (USAID), CARE International-Rwanda and Practical Action, have played a significant role. Viewed from the perspective of the innovation system as a whole, however, these interventions were unsystematic. For example, USAID conducted a stove performance testing programme, which ignored earlier efforts of model selection, and the capabilities developed by these efforts. Care International-Rwanda ran its Community Assisted Sustainable Energy (CASE) project focused on training rural women in the installation of rural improved cookstoves, with limited cooperation with other governmental and non-governmental actors. Again, development agencies focused on the *knowledge diffusion* and *knowledge* *development* functions, with a focus on selecting appropriate stove models, strengthening the capabilities of women and sensitizing the public to the potential benefits of improved stoves.

Table 4: Contributions of development agencies to the functioning of improved cookstove TISs in Rwanda (1980-2011).

	1980-1994	1995-2000	2001-2011	Total no. of events
Entrepreneurial activities	0	0	0	1
Knowledge development	1(100%)	1(100%)	**3(75%)**	**4**
Knowledge diffusion	**3(100%)**	**3(100%)**	**5(71%)**	**7**
Guidance of the search	0	0	1(25%)	4
Market formation	0	0	0	0
Resource mobilization	2(67%)	2(67%)	2(67%)	3
Creation of Legitimacy	0	0	0	0
Estimated diffusion rate (%/year)	0.18	0.15	1.09	

Note: The remarks under Table 3 also apply here.

In sum, an event analysis of the emergence of technology innovation systems of improved cookstoves in Kenya and Rwanda shows that ODA has played a very significant role over many decades. About 70% of events, recorded in detailed historical studies of these two cases, were supported by development agencies (calculated based on data in Table S1 and Table S2 in the Supplementary Material). The analysis also shows that the contribution of development aid was mainly targeted on a limited number of system functions over time, primarily *knowledge diffusion* and *knowledge development*, usually conceived of as separate – not connected – support mechanisms. Aid was not used to support the development of functionally balanced TIS, with strong functions across the seven functions identified in the literature. We observe that these systems remain fragile and dependent on international aid, despite aid support over about four decades. Finally, we observe that the level of cookstove diffusion in both countries has been well below expectations.

6 How can development aid contribute to building innovation systems?

We have argued that the build-up of mature and balanced technology innovation systems is key for the sustainable adoption and diffusion of renewable energy technologies in developing countries. We have also shown that past aid interventions were not focused on such a balanced development of innovation systems. The relevant question, therefore, is whether development agencies could contribute to innovation system-building in developing countries. In this section, we will set out a conceptual proposal for such support, based on our theoretical and empirical insights (see Table 5 for a brief representation of this proposal).

Table 5: Potential role for development aid in the functional buildup of renewable energy TIS in developing countries over time.

Maturity of technological innovation system	Weak	Emerging	Mature
Level of functional accumulation	System functions missing or a few functions served weakly	Some of the functions well-served	Balanced and mature accumulation of all functions
Role of development assistance	Supporting the emergence of system functions, with a focus on guidance of search, knowledge development and knowledge diffusion	Strengthening weak functions to support more balanced innovation system	Facilitating positive interactions between system functions
Relative importance of actors	Development partners and national policymakers	Development partners, local entrepreneurs and policymakers	Local actors specific to the TIS (business, industry associations, policymakers, research institutes, consumer bodies)

Our empirical evidence shows that the emergence of technological innovation systems is significantly shaped by development aid, which also steer the early growth of innovation systems. Two factors appear to play a major role in these early-stage contexts. First, the degree of alignment between the different factors influencing the emergence of innovation system functions appears important. A fit needs to exist between government policies, existing infrastructures, and the practices and capabilities of actors that may support the new technology (Tigabu et al., 2015c). Tigabu et al. (2015b) have observed that the *guidance of search* function, often driven by international agencies, major reports, conferences and national assessment studies, trigger governments to set targets and develop supportive policies, leading to the entry of other public actors and entrepreneurs into an emerging TIS. Therefore, gaining the political support of the recipient country and ensuring the development of a powerful *guidance of search* function appears to be important. This implies that regional and national authorities should be convinced that the technology promoted is feasible and capable of addressing existing economic, social or environmental challenges.

Technologies promoted without considering the needs and expectations of recipients are unlikely to promote robust innovation systems as a basis for effective technology diffusion. Specific actions that development agencies may support include the articulation of local demand for the specific technology, conducting feasibility research and supporting communication of its potential to meet a critical societal challenge, providing public recognition to lead-actors, encouraging the formation of industrial/technology associations and so on. Such activities support the creation of actor-coalitions supportive of a new technology which, in turn, may influence governments to take steps towards designing public policies and set adoption targets.

Strong and sustained guidance from government, in turn, encourages the entry of local actors with diversified resources and capabilities who may contribute to the adoption of the technology, system building and ultimately to the sustainability of interventions (see Tigabu et al., 2013b).

Second, support for weak or missing system functions appears to be important. This means that development aid support should attempt to encourage the eventual fulfillment of all needed system functions. In Table 6, we suggest interventions available to development agencies to encourage the fulfillment of a balanced set of TIS functions.

Table 6: Broad policy directions that development agencies may take to improve the functional performance of emerging TISs of renewable energy technologies in developing countries from the functions perspective.

Function	**Example policy directions for development aid**
Entrepreneurial activities	• Support the development and functioning of business incubation and training centers. • Development of sustainable business models for technology diffusion. • Public-private partnerships for risk-sharing in new business development.
Knowledge development	• Support stakeholder-driven technology assessment activities, linking needs to means. • Support research programmes in technical schools and technology institutes. • Encourage firms to undertake innovation activities.
Knowledge diffusion	• Support the development of platforms for technology demonstration. • Support the creation and functioning of training, extension and communication centers. • Facilitate the development of partnerships and networking among technology users and producers.

Guidance of the search	• Create credible political support for the technology. • Support the government to formulate favorable policy frameworks and regulations. • Encourage ways for articulation of demand and existing technical and resource potential for the technology.
Market formation	• Providing transparent information on costs, performance and economic potential for the technology • Create systematic ways for sharing user and producer costs of the new technology. • Facilitate the provision of appropriate incentives for technology adoption. • Support in the creation and functioning of organizations for quality checks and assurances, such as standard agencies.
Resource mobilization	• Support the provision of financial resources by local banks and micro-finance institutes and other financial sources. • Facilitate the development of innovative and sustainable financing mechanisms for projects. • Support the development of technical training curricula by technical and vocational schools or technology institutes. • Support the training and mobilization of technical experts • Support infrastructural development needed for new technology development and diffusion.
Creation of Legitimacy	• Support the formation of technology producer and user associations. • Encourage consistent political and institutional support across all TIS functions.

Where TIS functions are weak or absent, setting priorities may be important by taking into account the availability of financial, human and technological resources, as well as institutional capabilities. In the following, we set out a simple model through which ODA may be selectively focused on facilitating the development of TIS functions over time (see Figure 1 for a schematic representation).

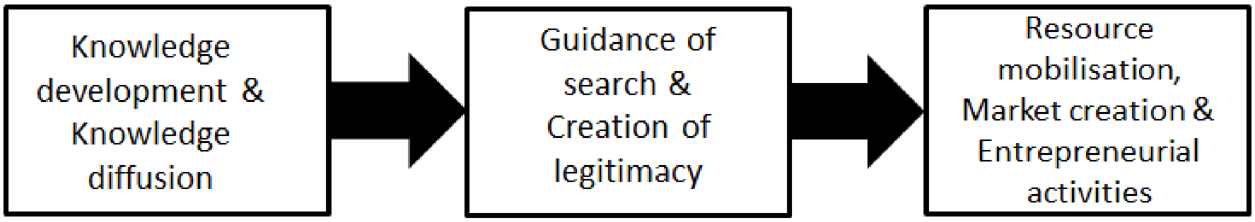

Figure 1: A proposed quasi-evolutionary 'model' of functional development as guide to ODA interventions supporting the functional development of 'weak' TIS

The special importance of the *guidance of search* function in inducing the development of other functions has already been noted. However, the *guidance of search* is contingent on other functions, including the *knowledge development* and *knowledge diffusion* (Tigabu et al., 2013b). For example, in the case of the early stage of the Rwandan biogas innovation system, the positive experiences of biogas installations in prisons and the associated development of awareness among policymakers, and encouraging results of a domestic biogas feasibility assessment induced the emergence of a strong *guidance of search* function (Tigabu et al., 2015a). This means that *knowledge development* and *knowledge diffusion* may be given a relatively higher priority over other innovation system functions at the very early stage of development, or for 'weak' TISs in terms of their functional accumulation (See Table 5). Once these functions are established (i.e. knowledge is developed and communicated), it would be important to ensure the confidence of entrepreneurs in a new and potentially risky sector, to counteract uncertainties, including the inertia from an already established and competitive sector. Therefore, the attention of development agencies needs then to turn to the *guidance of search* and *creation of legitimacy* functions. Specific activities that development agencies could support include public policy development, political support and coalition-building. An empirical example for this can be found in the case of biogas in Rwanda (Tigabu et al., 2015a). Development partners, including the German development agency, GIZ, supported the formulation of the Biomass Energy Strategy (BEST) following the knowledge on the feasibility of biogas to potential domestic and institutional customers. On the other hand, one way of stimulating the *creation of legitimacy* may be supporting the creation of private-public coalitions amongst potential producers and users. Trade associations may play several roles in the innovation system. For example, they may facilitate information exchange [*knowledge diffusion*] and learning through interaction and combination of experience-based insights [*knowledge development*]. The creation of associations may also allow actors to develop a shared vision about the future, as well as trust as a basis for cooperation in innovation, lobbying and market development. An example of this type of intervention can be found in both Kenyan cases and in the Rwandan biogas case (Tigabu et al., 2015b). In the Kenyan cases, for example, GIZ supported the formation of the Association of Biogas Contractors of Kenya (ABC-K). ABC-K has played a key role in the process of developing product standards for improved cookstoves and served as a platform for lobbying activities around biomass technologies in Kenya.

After the second stage, a minimum of four functions will be accumulated relatively (to other functions) and the TIS may be labeled as ‘emerging’ based on the level of its functional accumulation (see Table 5). Additionally, a new technology, which (potentially) meets actors’ positive expectations, would also be available, potentially inducing entry of entrepreneurs and increased attention from policymakers. However, three additional functions have to be fulfilled for the technology to diffuse and successfully capture market share. First, resources (both human and capital) are needed to be channeled sufficiently. Development agencies, therefore, need to facilitate the *resource mobilization* function. Specific actions for this function may include facilitating the provision of loans to producers and consumers by banks and other financial institutions. The Rwandan National Domestic biogas Program (NDBP) is a case in point (Tigabu et al., 2015a). Loans from Netherlands Development Finance Company (FMO) were made available to potential customers of domestic biogas reactors through a local bank, the Banque Populaire du Rwanda (BPR). Second, since the technology is new to the market, price/performance of the technology is likely to be poor and uncertain compared to existing alternatives. Additionally, the new technology may fail to compete with cheap but poor-quality products and alternatives. Therefore, market-stimulating interventions are needed to improve competitiveness gradually through learning and experimenting, while at the same time the market opportunity for producers is ensured. This means that ODA needs to facilitate the development of the *market formation* function. This can be done by facilitating and organizing systematic ways of sharing the cost of the new technology, enabling the development and enforcement of technical and other standards, and so on. Finally, it is important that technology producers, traders and other actors in the private sector continue to enter into the innovation system. New entrants, in addition to benefiting from the opportunities provided by the nascent innovation system, may require additional support to operate in the new sector. Development agencies should therefore create ways that nurture new entrants and support continued experimentation with the new technology. This can be done, for example, through the development of sustainable business models, incubation of new ventures, and so on.

The development of an innovation system is determined not only by system-building efforts among local actors and institutions, but also by efforts to remove obstacles to the development of functions (Bergek et al., 2008). It is well known that socio-economic barriers limit the creation of market enterprises and the diffusion of renewable energy technologies (Reddy and Painuly, 2004). Insights from Rural Energy Enterprise Development (AREED), a donor-funded project in Ghana and Senegal, show that development of commercially viable energy enterprises is constrained by financial, institutional, individual, social and cultural factors (Haselip et al., 2014; Haselip et al., 2015b). Johnson & Jacobsson (2001) have noted that such obstacles are often referred to as 'market failures' in conventional approaches. However, there are also other forms of failures or 'blockages'[3]. Blockages are linked to actors, networks, and institutional, market and contextual conditions of a technology that constrain the emergence and development of functions. Such blockages therefore lead to unbalanced or limited growth of a system and ultimately to 'system failure' (Bergek et al., 2008; Jacobsson & Bergek, 2011). Examples of blockages to innovation system functions in developing countries include insufficient trained labor or low levels of technical capability, lack of financial resources, vested interests, corrupt public administrations, uncompetitiveness (of technologies) relative to conventional alternatives, cultural and market preferences, limited infrastructure and limited linkages between the public and private sector organizations. It is important to identify and address such blockages in ways that are complementary to support for the functional development of innovation systems.

With favorable support, a balanced and 'mature' innovation system may gradually emerge (see Table 5). Existing research suggests that, at this stage, a process of self-reinforcing internal dynamics (interaction of functions) emerges (see e.g. Jacobsson & Bergek, 2004; Bergek et al., 2008). The major elements of the TIS structure fall into place and the roles of actors will become largely autonomous of development agencies and other external agents. The major task of

[3] Johnson & Jacobsson (2001) refer this as 'blocking mechanisms'.

development aid at this stage will be to ensure that the interaction of actors is maintained and new developments are communicated among actors to keep a momentum of positive interaction among functions. This will also be a phase in which ODA support is gradually removed.

Finally, we have argued that renewable energy innovation systems in developing countries are unique in terms of their functional accumulation pattern and path of evolution (Tigabu et al.,2013c). It is therefore difficult to generalize and the development path of different innovation systems will be, to some extent, unique. This specificity implies that policy interventions need to be tailored and responsive to the needs of each innovation system over time. This view is supported by Jacobsson & Bergek (2011) who have stressed the importance of 'technology-specific' policy interventions aimed at addressing system weaknesses. This requires monitoring and assessments of the strength and functioning of TIS functions and blockages through time and designing strategies aligned to the specific functional dynamics of the evolving system.

7 Conclusions

The aim of this paper is to reflect the role of official development aid in the evolution of renewable energy technologies in Africa, drawing on an innovation-systems approach to technology diffusion, and on evidence from the Kenyan and Rwandan improved cookstove innovation systems, and generates policy implications for ODA interventions. We have shown that development aid has driven a significant part of the major activities around improved cookstoves in the two countries over the last five decades. However, aid has been focused largely on supporting the *knowledge diffusion* and *knowledge development functions*. Aid has not been systematically used to support the development of balanced innovation systems over time. In many instances, we have observed that aid interventions have been isolated in time and space, addressing only a few actors without sufficiently considering their roles within the context of an emerging innovation system. We believe that aid would be more effective if it was implemented as a ‘concert’ of multiple interventions aimed at supporting, over time, the build-up of mature and balanced technology innovation systems.

Policy recommendations for development assistance are drawn directly from the weaknesses we have observed from the two cases. We have reiterated that it is important for development agencies, more generally, to recognize that innovation occurs in the context of an interacting network of actors influenced by specific institutional structures. This reinforces the importance of nurturing positive interactions among a range of local actors (from supply, demand, knowledge infrastructure and governance side). A system’s orientation is not sufficient. Encouraging the buildup of these systems and improving their functional performance is vital to improve uptake of renewable energy technologies. Hence, continued monitoring of the performance of functions in an innovation system is needed. The monitoring should include assessment on the presence, intensity and interaction of the key functions, including the blockages to the development of functions.

Supporting the build-up of innovation systems and achieving a transition to sustainable energy production and consumption is a resource-intensive and long-term commitment, which requires a compromise between short-term and long-term objectives. In other words, leapfrogging to a new energy system in the context of least-developed countries is elusive (Murphy, 2001). What is required is a consistent long-term system-building effort (Jacobsson & Bergek, 2004; Gallagher, 2006). Indeed, as Nichols (2007: 371) has put it, aid "… will be more effective to the degree that its programs look over the horizon."

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Appendix

Table A1: Number and categories of key informants.

Actor category	Kenya improved cookstove TIS	Rwandan improved cookstove TIS
Governmental	3	5
Non-governmental	10	8
Academic and research institute	3	3
Financial institute	0	1
Technology producer/enterprise	6	11
Total	22	28

Supplementary Materials

Table S1: Events and corresponding functions of the Kenyan improved cookstove TIS.

Year	**Incident**	**Function**	**Category of actor driving/financing the activity**
1976	The department of Physics of Kenyatta University College (KUC) carried out a household energy use survey.	Knowledge development	Academic/research institute
1976	KUC's household energy use survey showed that inefficient biomass use with crude technologies is contributing to the looming biomass crisis.	Guidance of search	Academic/research institute
1976	The government launched Appropriate Technology Center (ATC) within KUC to develop mechanisms of ensuring efficient consumption of biomass fuels.	Guidance of search	Government
1977	The ATC of KUC began stove design activities.	Knowledge development	Academic/research institute
1979	The Bellerive Foundation began research activities around household stoves.	Knowledge development	Donor/NGO
1980	Beijer Institute of Energy and Human Ecology conducted a large-scale wood-fuel consumption trend assessment in Kenya.	Knowledge development	Donor/NGO
1980	The study by Beijer Institute of Energy and Human Ecology on wood fuel use forecasted an impending wood-fuel crisis that urged the government to emphasize wood and charcoal use efficiency.	Guidance of search	Donor/NGO
1981	UNICEF developed Umeme charcoal stove.	Knowledge development	Donor/NGO
1981	Bellerive Foundation of Geneva developed Micuta Jiko.	Knowledge development	Donor/NGO
1981	Kenya clay working group (KCWG) worked on designing stove models with features of traditional Kenyan stoves and Thai-bucket stoves.	Knowledge development	Donor/NGO
1981	A United Nations Conference on New and Renewable Sources of Energy (UNCNRSE) was held in Nairobi.	Knowledge diffusion	Donor/NGO
1981	In the UNCNRSE promotion of improved cookstove was stressed.	Guidance of search	Donor/NGO
1981	In the UNCNRSE, exhibition/demonstration of stove models was made.	Knowledge diffusion	Donor/NGO
1981	UNICEF's Umeme stove received a prize as the best design of improved cookstove on the conference.	Guidance of search	Donor/NGO
1981	International Development Research Center (IDRC) provided a grant of KES 85,000 to Maxwell Kinyanjui.	Resource mobilization	Donor/NGO
1981	Kenya Renewable Energy Development Project (KREDP) allocated $ 160,000 for improved cookstove.	Resource mobilization	Donor/NGO
1981	KREDP conducted surveys of existing stove activities.	Knowledge development	Donor/NGO
1981	The results from the KREDP surveys suggested that concentrating on urban charcoal stoves is best initial strategy.	Guidance of search	Donor/NGO

1981	KREDP tested fuel-saving efficiency of various Thai cookstove designs.	Knowledge development	Donor/NGO
1982	Experience-sharing tour to Thailand to learn from the experiences of the Thai stoves industry was made under KREDP.	Knowledge diffusion	Donor/NGO
1982	The tour to Thailand was funded by USAID and the Beijer Institute.	Resource mobilization	Donor/NGO
1982	Intermediate Technology Development Group (ITDG) employed two part-time workers for improved charcoal stove design and development.	Resource mobilization	Donor/NGO
1982	KREDP employed Maxwell Kinyanjui	Resource mobilization	Donor/NGO
1982	KREDP successfully developed the Kenyan Ceramic Jiko (KCJ) model	Knowledge development	Donor/NGO
1982	Jerri International fabricated initial samples of KCJ prototypes for field-testing.	Entrepreneurial activities	Private sector
1982	Dr. Raphael Kapiyo carried out the field-testing of the KCJ prototype.	Knowledge development	Private sector
1982	Bell-bottom shaped design of the KCJ was developed by KREDP.	Knowledge development	Donor/NGO
1983	KENGO trained selected fundis on the production of KCJ.	Knowledge diffusion	Donor/NGO
1983	KRDP offered partial investment cost to 30 artisans.	Resource mobilization	Academic/research institute
1983	KRDP also provided shed and indoor masonry kiln to some of the fundis.	Resource mobilization	NGO
1983	KENGO campaigned about improved cookstove.	Knowledge diffusion	NGO
1983	KENGO distributed 5000 booklets with information on the importance of the KCJ.	Knowledge diffusion	NGO
1983	KENGO sensitized over 240 policymakers, district administrators and development extensionists, NGO heads and teachers.	Knowledge diffusion	Donor/NGO
1983	Ministry of Energy (MOE) conducted exhibition of KCJ	Knowledge diffusion	Government
1983	The Kenyan army conducted a KCJ distribution program to the soldiers resulting in awareness development in the society	Knowledge diffusion	Government
1983	New entrepreneurs entered in improved cookstove business.	Entrepreneurial activities	Private sector
1983	German Agency for Technical Cooperation (GTZ) funded Special Energy Program (SEP) stove program	Resource mobilization	Donor/NGO
1985	SEP program designed Maendeleo woodstove.	Knowledge development	Donor/NGO
1985	SEP trained Maendeleo ya Wanawake women group in the manufacturing of the Maendeleo stoves and business management.	Knowledge diffusion	Donor/NGO
1985	Maendeleo ya Wanawake began commercial production of Maendeleo stoves.	Entrepreneurial activities	NGO
1985	KENGO designed Kuni Mbili.	Knowledge development	NGO
1985	Norwegian Agency for Development Cooperation (NORAD) and CARE International and Appropriate Technology International (ATI)	Resource mobilization	Donor/NGO

	funded the research work of Kuni Mbili.		
1985	KENGO began research on the development of institutional stoves	Knowledge development	NGO
1985	IDRC funded KENGO's institutional stove design and development research.	Resource mobilization	Donor/NGO
1985	United Nations Environment Programme (UNEP) provided a grant of KSH 1.5 million to Bellerive Foundation to undertake institutional stove development research.	Resource mobilization	Donor/NGO
1985	CARE International trained Keyo Women Group on improved ceramic liner production.	Knowledge diffusion	Donor/NGO
1985	Ministry of Agriculture's extension officers in home economics and agriculture promoted improved cookstove.	Knowledge diffusion	Government
1985	GTZ funded the improved cookstove promotion by extension officers in home economics and agriculture.	Resource mobilization	Donor/NGO
1985	ATI provided a grant of KSh 4,065,500 to KENGO to facilitate the introduction of KCJ outside of Nairobi.	Resource mobilization	Donor/NGO
mid 1985 to mid 1988	KENGO trained stove producers.	Knowledge diffusion	Donor/NGO
mid 1985 to mid 1988	KENGO provided loan to stove producers.	Resource mobilization	Donor/NGO
1986	KENGO and the MOE organized workshop in Nairobi on improved cookstove	Knowledge diffusion	Donor/NGO
1989	ITDG funded Rural Stoves West Kenya (RWSK) project.	Resource mobilization	Donor/NGO
1989	RWSK developed Maendeleo portable.	Knowledge development	Donor/NGO
1989	RWSK trained women groups.	Knowledge diffusion	Donor/NGO
1990	Three key figures in the improved cookstove development and promotion in Kenya, particularly for designing and promoting the KCJ won Innovations for Development Award (IDEA) award.	Guidance of search	Donor/NGO
1995	Renewable Energy Technology Assistance Programme (RETAP) conducted institutional energy needs assessment survey.	Knowledge development	Donor/NGO
1995	RETAP study led to the formation of RETAP's revolving fund with initial money provided by GEF/SGP-UNDP.	Resource mobilization	Donor/NGO
1995	ITDG funded Upesi project.	Resource mobilization	Donor/NGO
1995	Upesi project trained women women on Upesi stove production and installation.	Knowledge diffusion	Donor/NGO
1995	Trained promoters campaigned in homes, churches, market places and so on.	Knowledge diffusion	Donor/NGO
1995	ITDG funded a radio promotion of Upesi stove.	Resource mobilization	Donor/NGO
1995	Upesi stoves were promoted through radio.	Knowledge	Donor/NGO

		diffusion	
1996	Agroforestry Centers renamed as Energy Centers, showing the shift in focus of renewable energy technologies .	Guidance of search	Government
1997	ITDG offred a motor cycle loan to Upesi producers.	Resource mobilization	Donor/NGO
1997	The motor cycles carried Upesi promotional messages	Knowledge diffusion	Government
1997	Quality stamps, t-shirts and a bicycle loan were offered to promoters selling over 100 stoves.	Market formation	Government
2000	Stoves and Household Energy (SHE) Programme trained women in improved ceramic stove production.	Knowledge diffusion	Government
2002	MOE conducted a biomass energy demand and supply assessment.	Knowledge development	Government
2003	White Paper on Energy Policy Draft 1 specified targets of improved cookstove penetration.	Guidance of search	Government
2004	The Sessional Paper No. 4 on Energy reflected measures of increasing rate of adoption.	Guidance of search	Government
2005	Netherlands Directorate General of Development (DGIS) funded a improved cookstove program run by GTZ.	Resource mobilization	Donor/NGO
2005	GTZ's improved cookstove program trained women groups in ceramic liner production.	Knowledge diffusion	Donor/NGO
2006	Energy Act of 2006 encouraged the promotion of improved cookstove.	Guidance of search	Government
2006	GIZ-PSDA program trained Rocket stove and Jiko Kisasa stove.	Knowledge diffusion	Donor/NGO
2007	Global Village Energy Partnership (GVEP) began its Developing Energy Enterprises Program (DEEP) funded by DGIS and the European Union (EU).	Resource mobilization	Donor/NGO
2007	DEEP campaigned about improved cookstove.	Knowledge diffusion	Donor/NGO
2007	Key players in improved cookstove began lobbying for improved policy environment.	Creation of legitimacy	Private sector
2007	Efforts of improved cookstove standard began.	Market formation	Private sector
2008 - 2010	GIZ-PSDA campaigned about improved cookstove.	Knowledge diffusion	Donor/NGO
2008 - 2010	GIZ-PSDA provided subsidies to improved cookstove producer groups.	Resource mobilization	Donor/NGO
2010	GIZ-PSDA contributed to the creation of over, 780 private businesses around improved cookstove.	Entrepreneurial activities	Donor/NGO
2011	Partnership for Clean Indoor Air (PCIA) awarded the stove component of GIZ-PSDA program.	Guidance of search	Donor/NGO

Table S2: Events and corresponding functions of the Rwandan improved cookstove TIS.

Year	Incident	Function	Category of actor driving/financing the activity
Early 1980s	Energy Directorate of Rwanda appointed a	Resource	Government

	cconsultant.	mobilization	
1987	Funding was made available by Netherlands Development Assistance Agency (SNV) ($ 95,000)	Resource mobilization	Donor/NGO
1987	SNV and the Ministry of Public Works and Energy campaigned about improved cookstoves	Knowledge diffusion	Donor/NGO
	The World Bank's Energy Sector Management Assistance Program (ESMAP) carried out stove performance testing being supervised by the Ministry of Public Works and Energy	Knowledge development	Donor/NGO
1988	ESMAP trained private stove-makers	Knowledge diffusion	Donor/NGO
1988	ESMAP also provided production tools to stove artisans	Resource mobilization	Donor/NGO
1990	ESMAP conducted public complaining activities	Knowledge diffusion	Donor/NGO
2005	Rwanda Defence Forces RDF in collaboration with the Ministry of Local Government (MINALOC) conducted rural ICS dissemination campaign	Knowledge diffusion	Government
2005	Kigali Institute of Science and Technology (KIST) carried out woodfuel uses assessment	Knowledge development	Academic/research institute
2005	The fuel-use assessment result created a sense of urgency of intervening and led to the development of new policies	Guidance of search	Academic/research institute
	United States Agency for International Development (USAID) conducted performance assessment of existing models	Knowledge development	Donor/NGO
2007	Economic Development and Poverty Reduction Strategy (EDPRS) set targets of improved cookstove adoption	Guidance of search	Donor/NGO
2008	The government formulated the biomass energy strategy (BEST) in collaboration with Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) and EUEI Partnership Dialogue Facility	Guidance of search	Government
2008	Community Assisted Sustainable Energy (CASE) project, run by CARE International-Rwanda trained stove producers	Knowledge diffusion	Donor/NGO
2008	Community Assisted Sustainable Energy (CASE) also campaigned about ICS	Knowledge diffusion	Donor/NGO
2010	Practical Action Consulting and Ministry of Infrastructure conducted feasibility studies for urban and rural improved cookstove promotion	Knowledge development	Donor/NGO
2010	Newspapers reported that ICS promotion to be a focus of the government	Guidance of search	Private sector
2011	Rwanda Development Board (RDB) began training stove producers on small business	Knowledge diffusion	Government

	management		
2011	Blacksmiths and new enterprises entered and began producing ICSs	Entrepreneurial activities	Private sector